MDOB Role in FY 98 NASA Programs

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Outline

- NASA Aeronautics & Space Transportation Technology Strategy
- NASA Langley Research Center (LaRC) Organization
- MDOB FY 98 Activities
  - HPCCP Computational AeroSciences (CAS)
  - Airframe Systems Concept to Test (ASCOT)
  - Aircraft Morphing
  - Reusable Launch Vehicles (RLV)

NASA Aeronautics and Space Transportation Technology Strategy

NASA Aeronautics and Space Transportation Technology Strategy

- **NASA Strategic Plan**
  - **http://www.hq.nasa.gov/office/nsp/**
- **NASA Office of Aeronautics and Space Transportation Technology (OASTT)**
  - **http://www.hq.nasa.gov/office/aero/**
- **NASA OASTT Three Pillars for Success**
  - **http://www.hq.nasa.gov/office/aero/oastthp/brochure/brochure.htm**
  - **the 10 specific goals are listed on the following 3 slides**

Pillar One: Global Civil Aviation

- Reduce the aircraft accident rate by a factor of five within 10 years, and by a factor of 10 within 20 years
- While maintaining safety, triple the aviation system throughput, in all weather conditions in 10 years
- Reduce emissions of future aircraft by a factor of three within 10 years, and by a factor of five within 20 years
- Reduce the perceived noise levels of future aircraft by a factor of two from today's subsonic aircraft within 10 years, and by a factor of four within 20 years
- Reduce the cost of air travel by 25% within 10 years, and by 50% within 20 years

Pillar Two: Revolutionary Technology Leaps

- **Provide next-generation design tools and experimental aircraft to increase design confidence, and cut the development cycle time for aircraft in half**
- **Invigorate the general aviation industry, delivering 10,000 aircraft annually within 10 years, and 20,000 aircraft annually within 20 years**
- **Reduce the travel time to the Far East and Europe by 50% within 20 years, and do so at today's subsonic ticket prices**

Pillar Three: Access to Space

- Reduce the payload cost to Low Earth Orbit by an order of magnitude, from $10,000 to $1,000 per pound, within 10 years
- Reduce the payload cost to Low Earth Orbit by an additional order of magnitude, from $1,000's to $100's per pound, by 2020

NASA Aeronautics & Space Transportation Technology Programs
(Lead Centers)

- **High Speed Research (LaRC)**
  - **http://www.lerc.nasa.gov/Other_Groups/HSR/wings_to_come.html**
- **Advanced Subsonic Technology (LaRC)**
  - **http://ast-server.larc.nasa.gov/**
- **High Performance Computing and Communications (ARC)**
  - **http://www.aero.hq.nasa.gov/hpcc/**
- **Space Transportation (MSFC)**
  - **http://astp.msfc.nasa.gov/**
- ***Aircraft Safety Research [FY 00 start] (LaRC)***
  - **http://www.hq.nasa.gov/office/aero/oastthp/curevent/asist.htm**

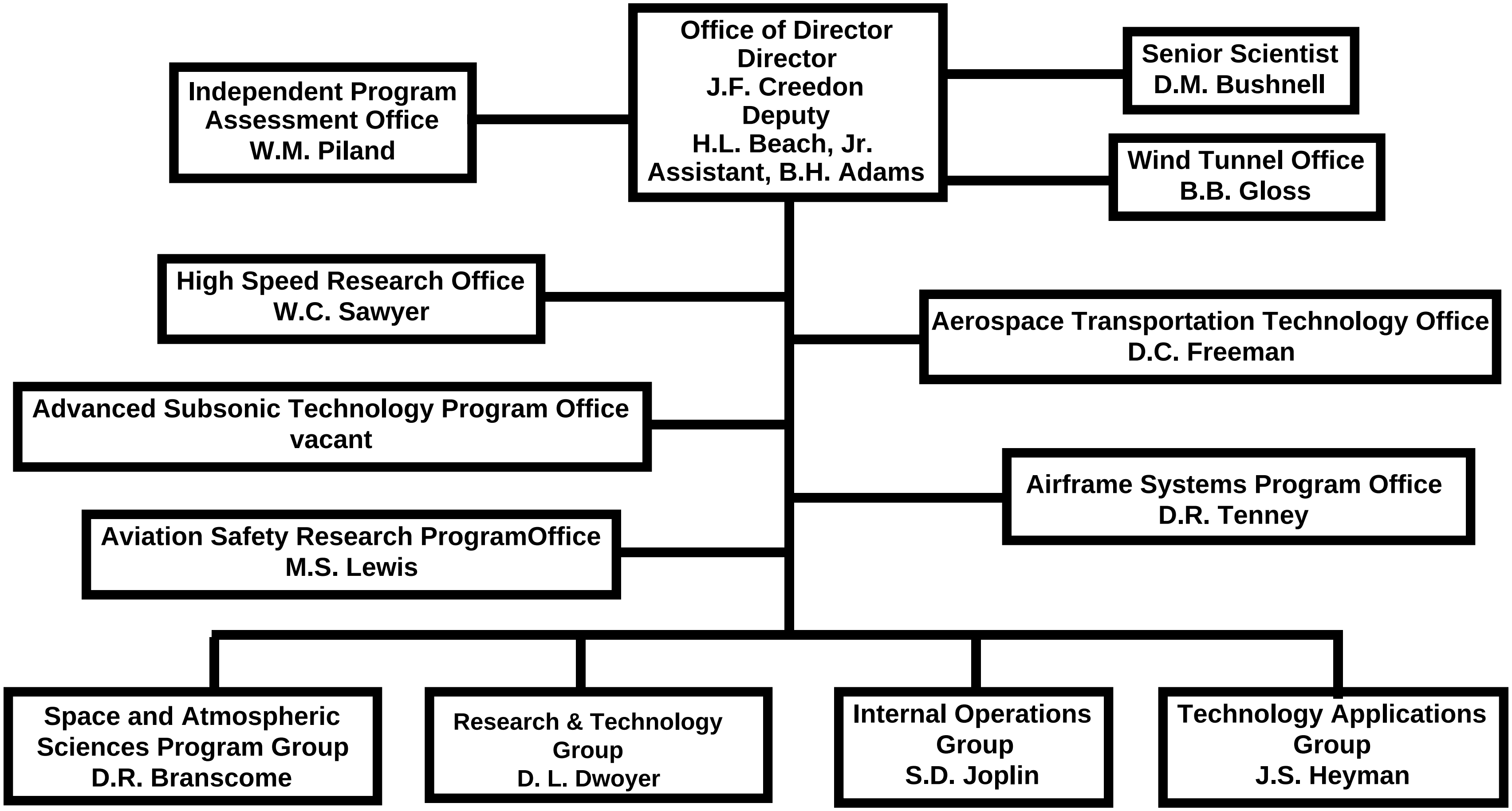
NASA Aeronautics & Space Transportation Technology Programs

(Lead Centers)

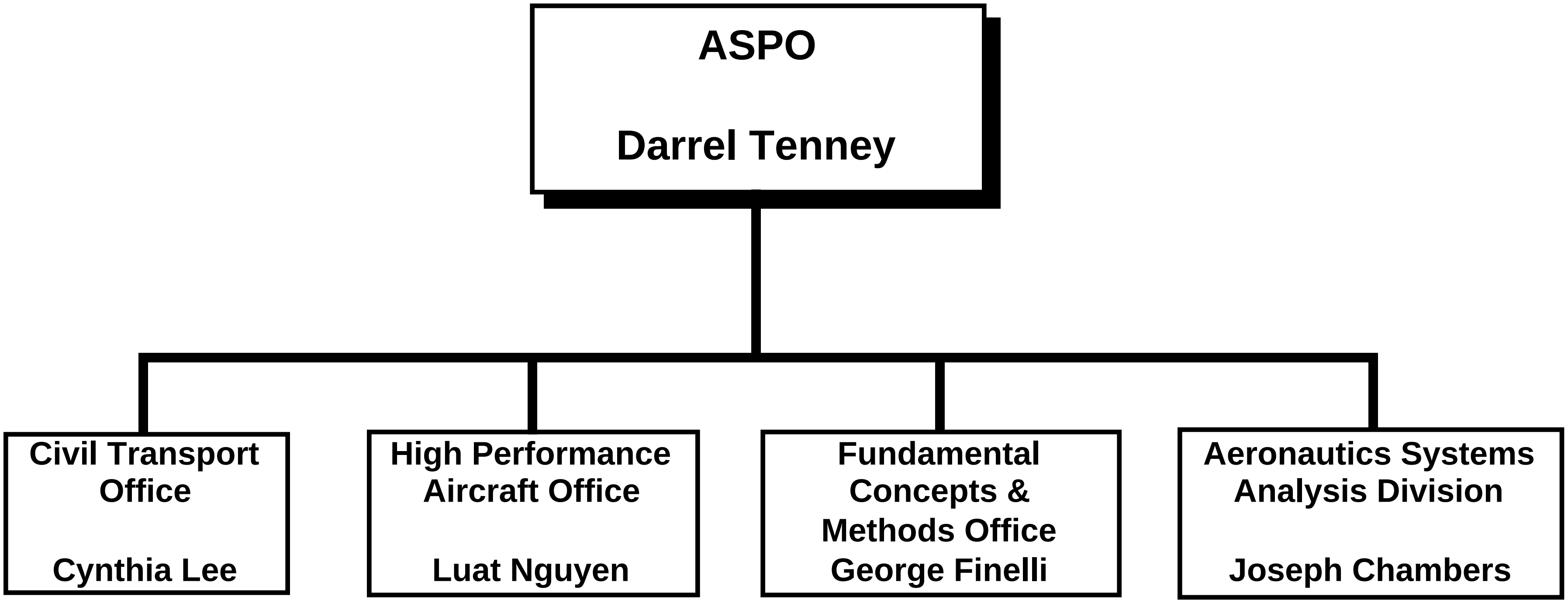
- **Research & Technology Base**
  - **Airframe Systems (LaRC)**
  - **Propulsion (LeRC)**
    - **http://www.lerc.nasa.gov/WWW/AERO/base/psbase.htm**
  - **Aviations Operations Systems (ARC)**
  - **Rotorcraft (ARC)**
  - **Flight Research (DFRC)**
    - **http://www.dfrc.nasa.gov/Aero/index.html**
  - **Information Technology (ARC)**

NASA Langley Research Center Organization

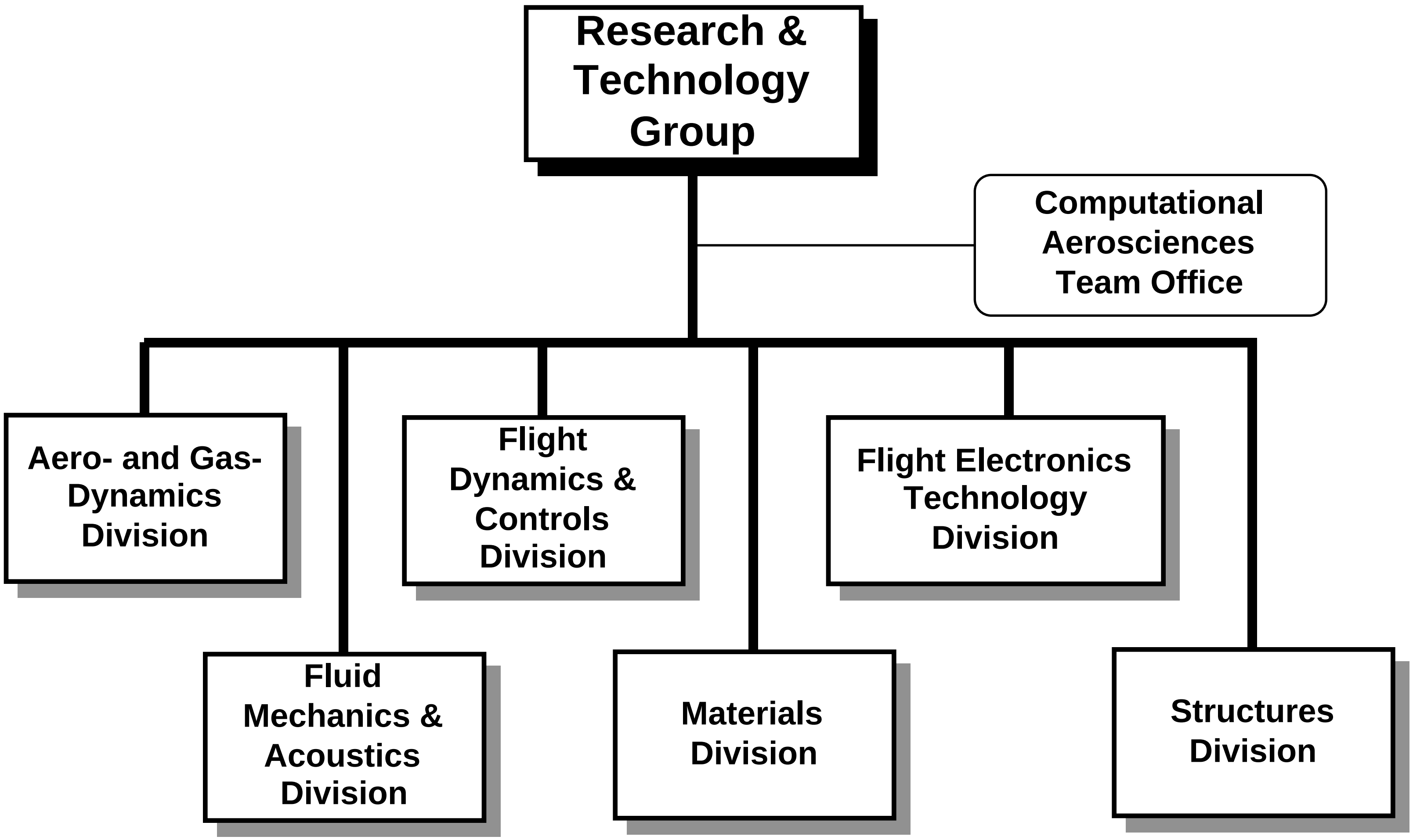
LaRC Organization



Airframe Systems Program Office



Research and Technology Group



NASA Program Overviews

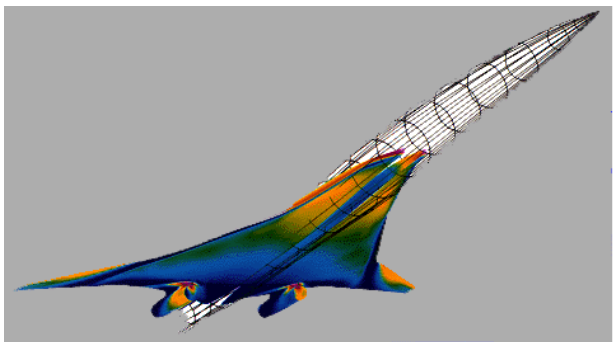
High Performance Computing and Communications

Computational AeroSciences Program

LaRC CAS Program Manager: Jarek Sobieski

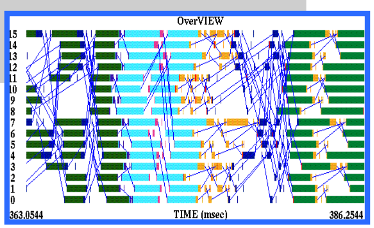
HPCCP CAS Workdown Structure - Four Areas

Grand Challenge Applications and Algorithms

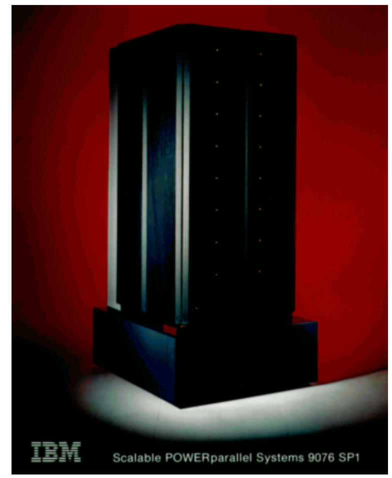


System Software Research and Development

```
main()
{
        printf(“hello,
        world\n”);
}
```



Computing Testbeds



Basic Research and Human Resources

CAS Mission Statement

CAS Mission is to:

- Accelerate development and availability of high performance computing technology of use to the U.S. aerospace community,
- Facilitate adoption and use of this technology by the U.S. aerospace industry, and
- Hasten emergence of a viable commercial market for hardware and software vendors to exploit this lead.

CAS is a computing and communications technology focused program oriented around the needs of the aeroscience community.

It is not a CFD program.

NASA Programs Overview

Airframe Systems Base

NASA Program Manager: Darrel Tenney

NASA Airframe Systems Base
Level 2 Programs

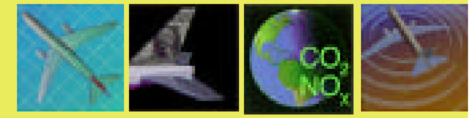
- Civil Transport Office
  - Integral Airframe Structures (IAS)
  - Futuristic Airframe Concepts & Technology (FACT)
  - Advanced Life Extension (ALEX)
  - Error-Proof Flight Deck (Error-Proof)
  - Advanced Subsonic Technology Aircraft (ASTAR)
- High Performance Aircraft Office
  - Aircraft Tactical Technology from Advanced Controls (ATTAC)
  - Methods for Affordable Design (MAD)
  - Uninhabited Combat Air Vehicles (UCAV)
  - Cloaking for Survivability (CLOSUR)
- Fundamental Concepts and Methods Office
  - Airframe Systems Concept to Test (ASCOT)
  - Morphing
  - Total Aircraft Management Environment (TAME)
- Hypersonics
  - Hyper-X

Airframe Systems Base
Level 2 Programs

Airframe Systems Concept to Test
(ASCOT)

LaRC Program Manager: Long P. Yip

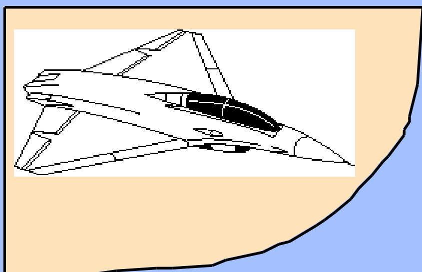
ASCOT (Airframe Systems COncept to Test)

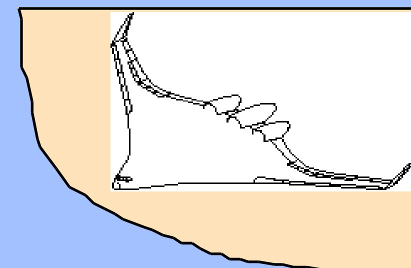


Goal: Revolutionary Methods for Complete Aircraft Design

Objective: Develop Analysis & Design Tools that Overcome Barrier Technology Issues

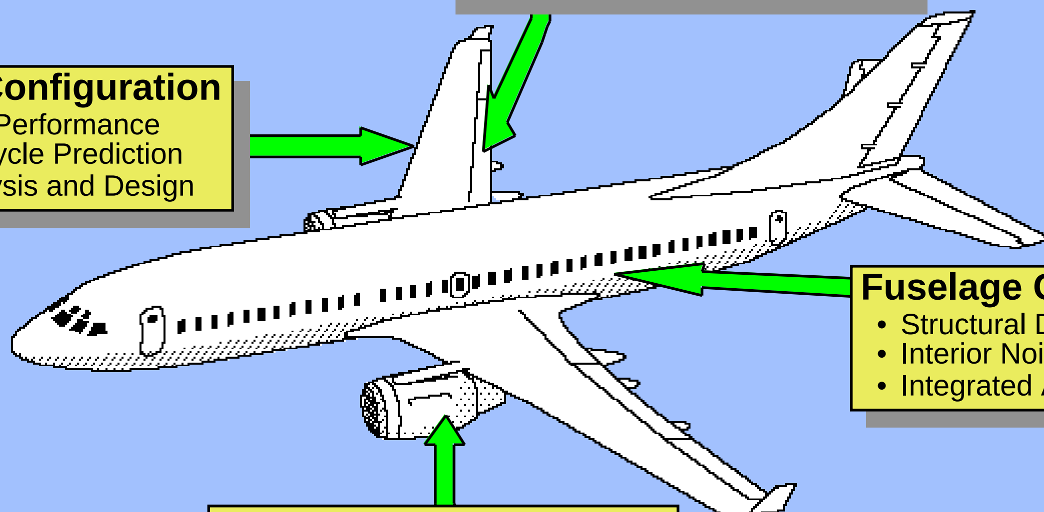
Fundamental Understanding / Integrated Approach ⇒ Fast, Accurate, Reliable Methods





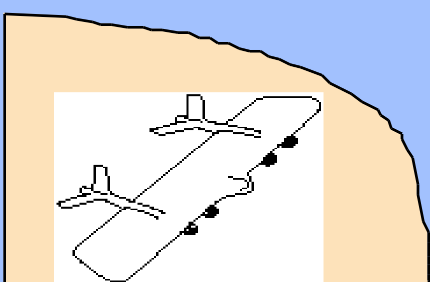
High-Lift Systems
- Performance
- Airframe Noise
- Integrated Analysis and Design

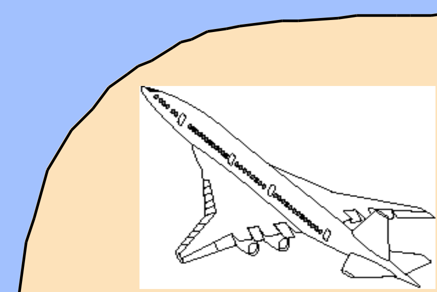
Cruise Wing Configuration
- Aero/Structural Performance
- Buffet & Limit Cycle Prediction
- Integrated Analysis and Design



Fuselage Components
- Structural Design
- Interior Noise
- Integrated Analysis and Design

Engine Components
- Noise & Emissions
- Performance
- Integrated Analysis and Design

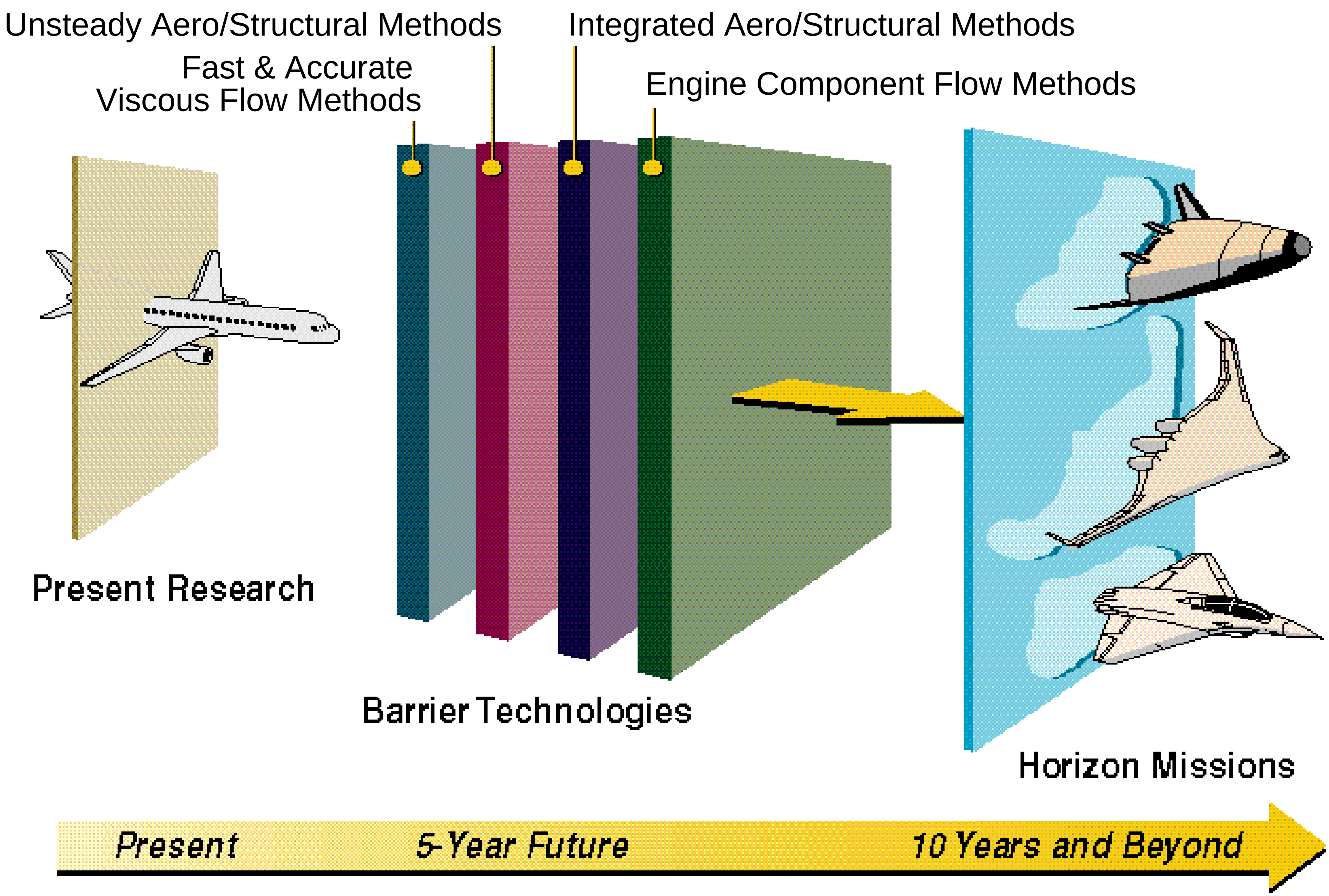




ASCOT (Airframe Systems COncept to Test)

Goal: Revolutionary Methods for Complete Aircraft Design

Objective: Develop Analysis & Design Tools that Overcome Barrier Technology Issues



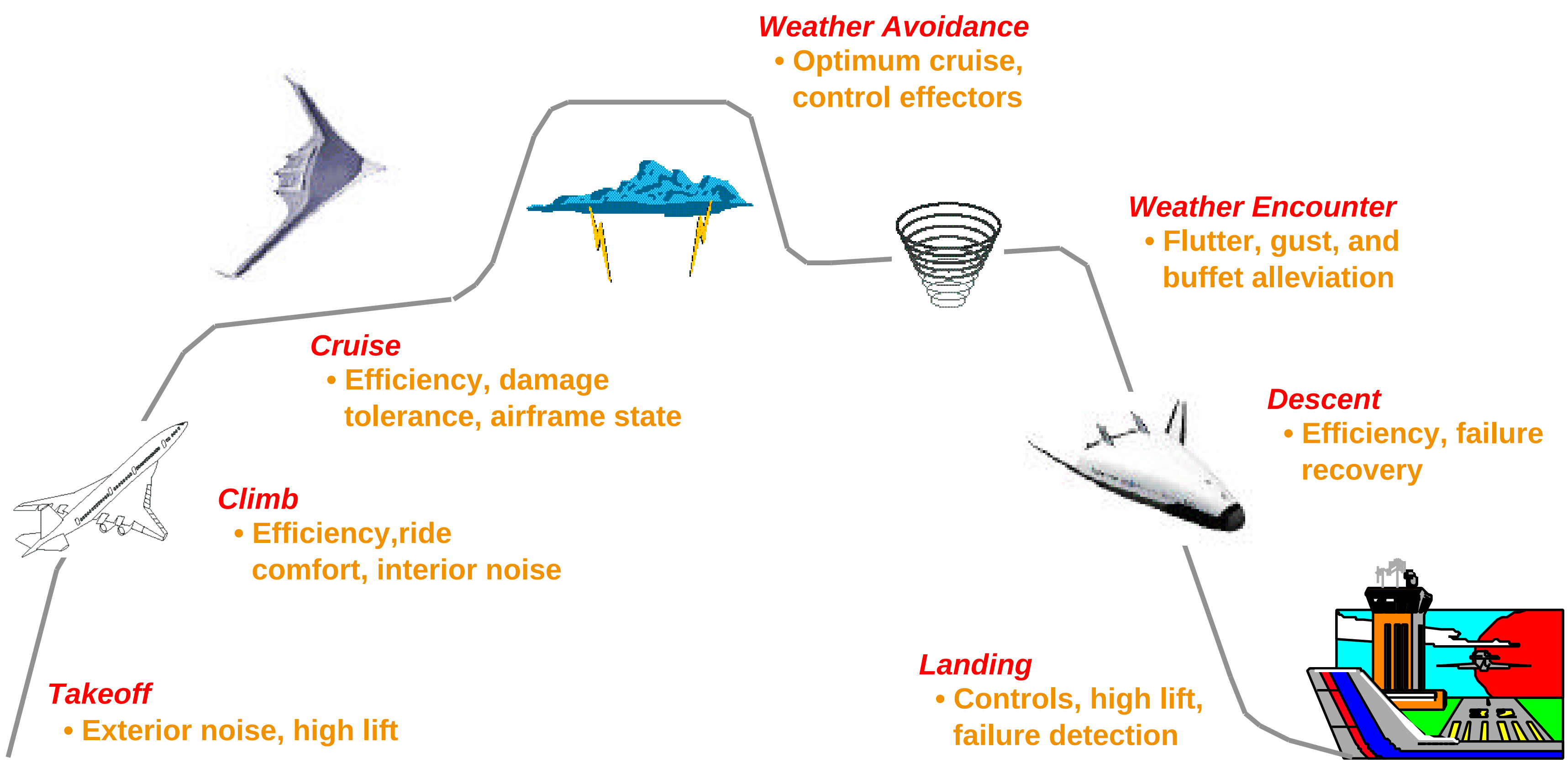
Airframe Systems Base
Level 2 Programs

Aircraft Morphing

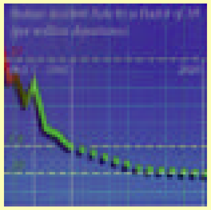
LaRC Program Manager: Richard W. Wlezien

Aircraft Morphing Goal and Vision

Develop active component technologies that enable self-adaptive flight for a revolutionary improvement in environmental compatibility, aircraft safety, affordability, and performance by 2002.



Program Sub-Elements



reduce aircraft accident rate

1. **Embedded technologies for airframe monitoring and healing for increased flight safety**

environmental compatibility

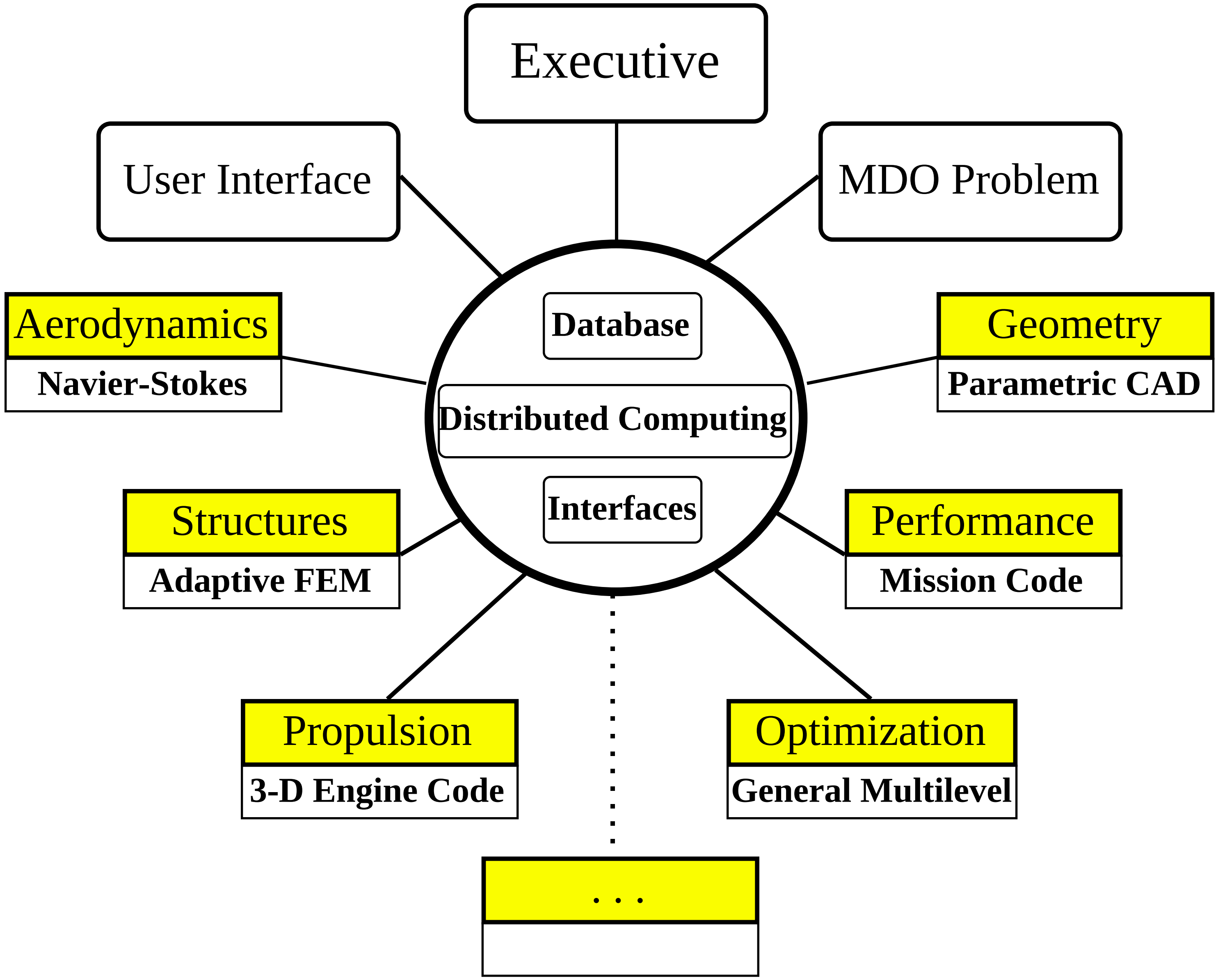
2. **Component technologies which enable environmentally compatible integrated self-adaptive airframes**

next-generation design tools

3. **Smart airframe design, integration, and system analysis**

MDOB HPCCP CAS Activities

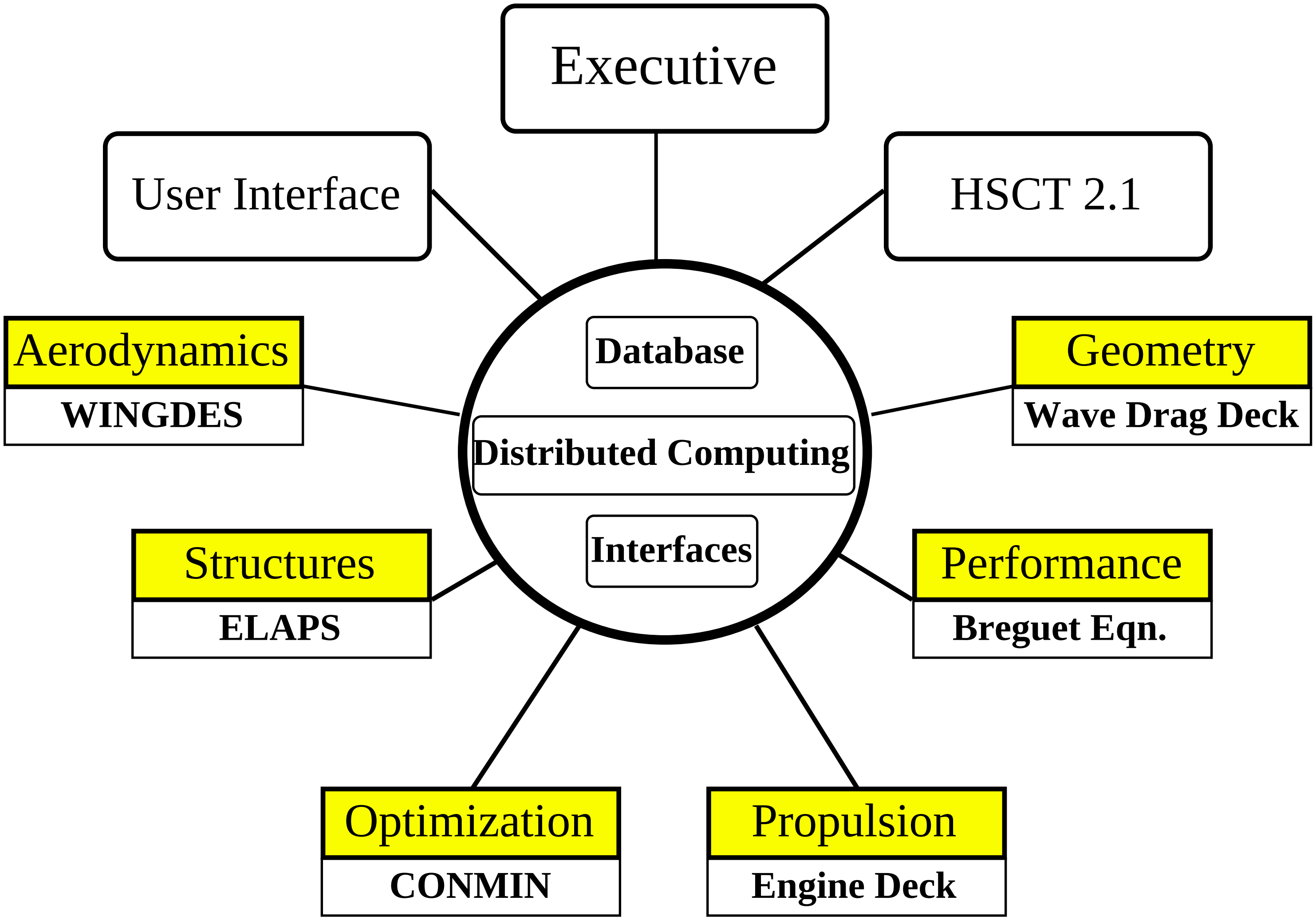
HPCCP HSCT Application Goal



HPCCP MDO Framework

- FIDO
  - this in-house MDO Framework for High Performance Computing started in 1992
  - the project was initiated when no suitable commercial frameworks were available
  - one goal was to identify critical issues in framework development
  - HPCCP & MDOB now desire to transition to a commercial framework
- iSIGHT
  - marketed by Engineous Software, Inc.
  - HPCCP & MDOB have purchased several licenses and are in the midst of evaluating the product on HSCT 2.1 & HSCT 3.5

HSCT 2.1


Executive
User Interface
HSCT 2.1
Database
Distributed Computing
Interfaces
Aerodynamics
WINGDES
Geometry
Wave Drag Deck
Structures
ELAPS
Performance
Breguet Eqn.
Optimization
CONMIN
Propulsion
Engine Deck

HSCT 2.1

Structures: Equivalent Plate (ELAPS), o(100) DOF's,
Variables: 2, inboard/outboard skin thicknesses

Aero: Panel (WINGDES), o(1000) DOF's,
Variables: 3, sweep, span and chord at break

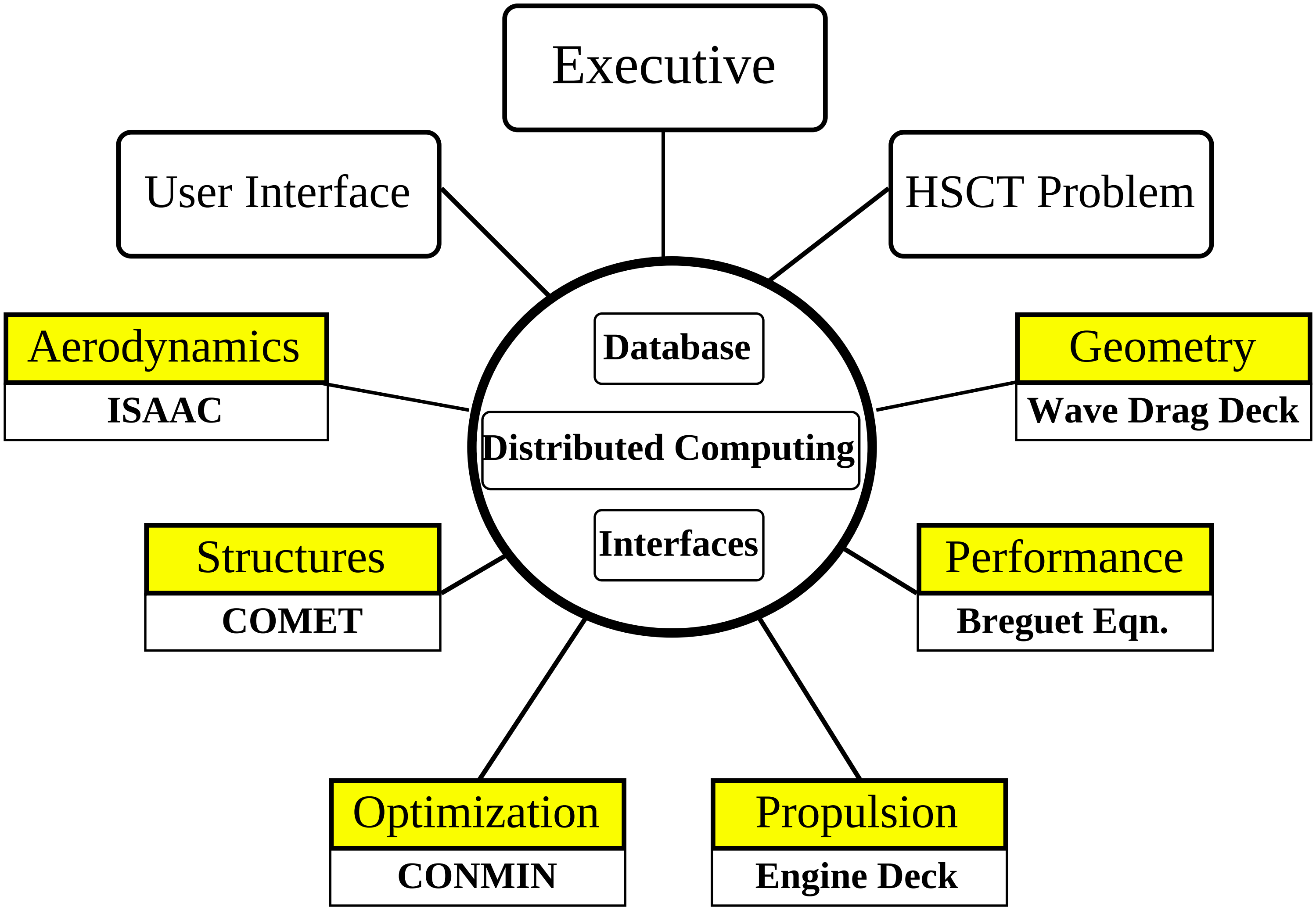
Framework: FIDO and iSIGHT

Status: available, no proprietary software (FIDO version)

Platform: single workstation SUN (Solaris), IBM (AIX) *or*
heterogeneous cluster of workstations (FIDO version)

Pros	Cons
• turnaround time o(30min/cycle)	• notional wing-only a/c concept
• robust implementation	• simple design problem
• used as IMAGE demo by GIT	• Breguet performance

HSCT 3.5



Executive
User Interface
HSCT Problem
Database
Distributed Computing
Interfaces
Aerodynamics
ISAAC
Geometry
Wave Drag Deck
Structures
COMET
Performance
Breguet Eqn.
Optimization
CONMIN
Propulsion
Engine Deck

HSCT 3.5

Structures: FEM (COMET), o(15000) DOF's,
Variables: 4, inbd/outbd skin thickness distributions

Aero: Marching Euler (ISAAC), o(15000) gridpoints,
Variables: 3, sweep, span and chord at break

Framework: FIDO (iSIGHT coming on-line, 10/97)

Status: available, no proprietary software (FIDO version)

Platform: heterogeneous cluster of workstations (FIDO version)

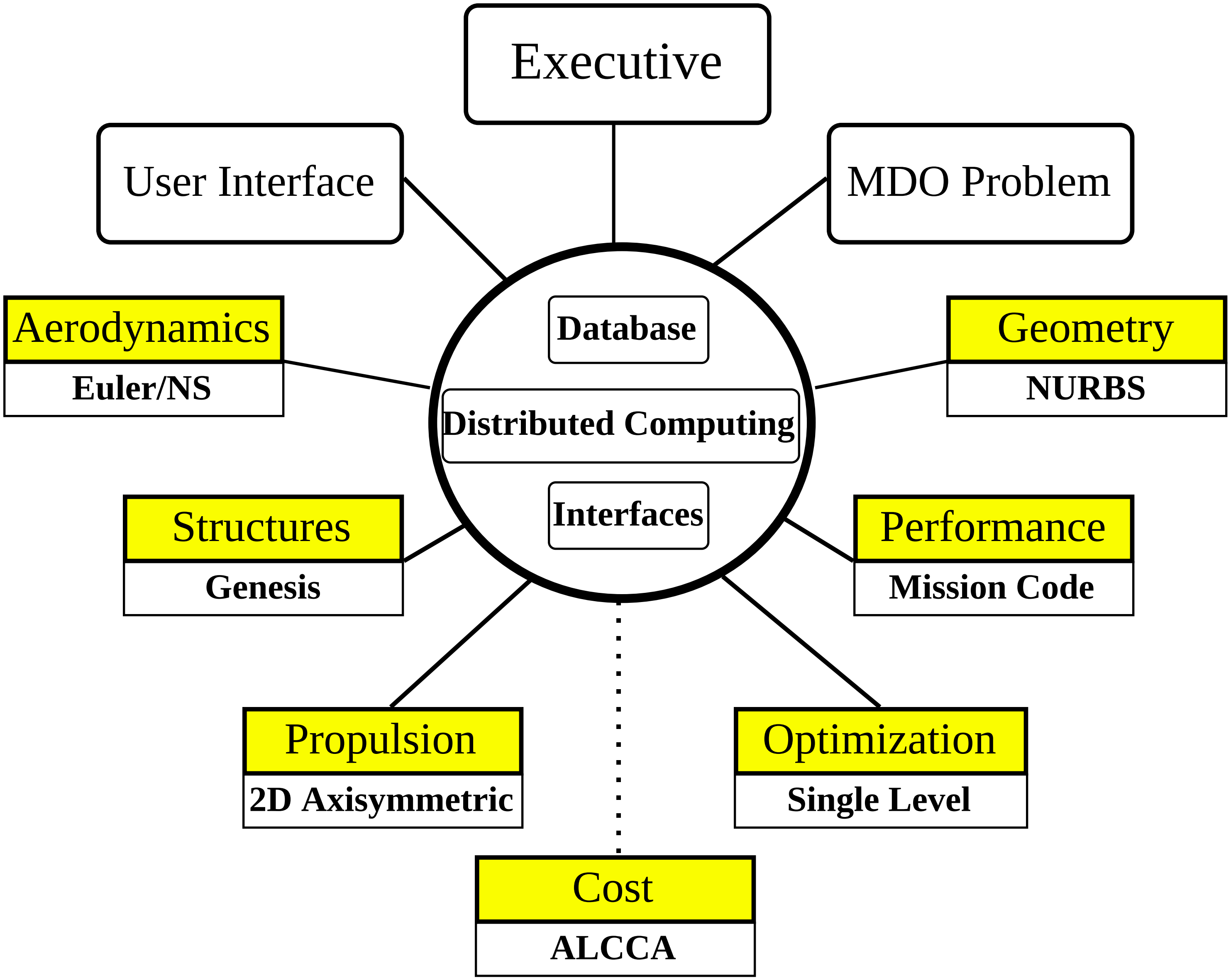
Pros

- turnaround time o(3hrs/cycle)
- representative simulations
- reasonable model sizes

Cons

- notional a/c concept
- simple design problem
- Breguet performance

HSCT 4.0


Executive
User Interface
MDO Problem
Database
Distributed Computing
Interfaces
Aerodynamics
Euler/NS
Geometry
NURBS
Structures
Genesis
Performance
Mission Code
Propulsion
2D Axisymmetric
Optimization
Single Level
Cost
ALCCA

HSCT 4.0

Structures: FEM (Genesis?), plate elements, o(40000) DOF's,
Variables: up to ~100 (plies, sandwich thicknesses)

Aero: Euler/Navier Stokes (CFL3D), o(10^5-10^6) nodes,
Variables: up to ~100,

Framework: FIDO during FY 98, perhaps transitioning to iSIGHT in FY 99

Status: initial capability anticipated 6/98

Platform: massive parallel architecture (Origin 2000's)
heterogeneous cluster of large-memory workstations

Pros

- representative models
- FLOPS performance
- propulsion simulation
- intermed. complexity design

Cons

- not on-line
- turnaround time o(3day/cycle)
- proprietary a/c model

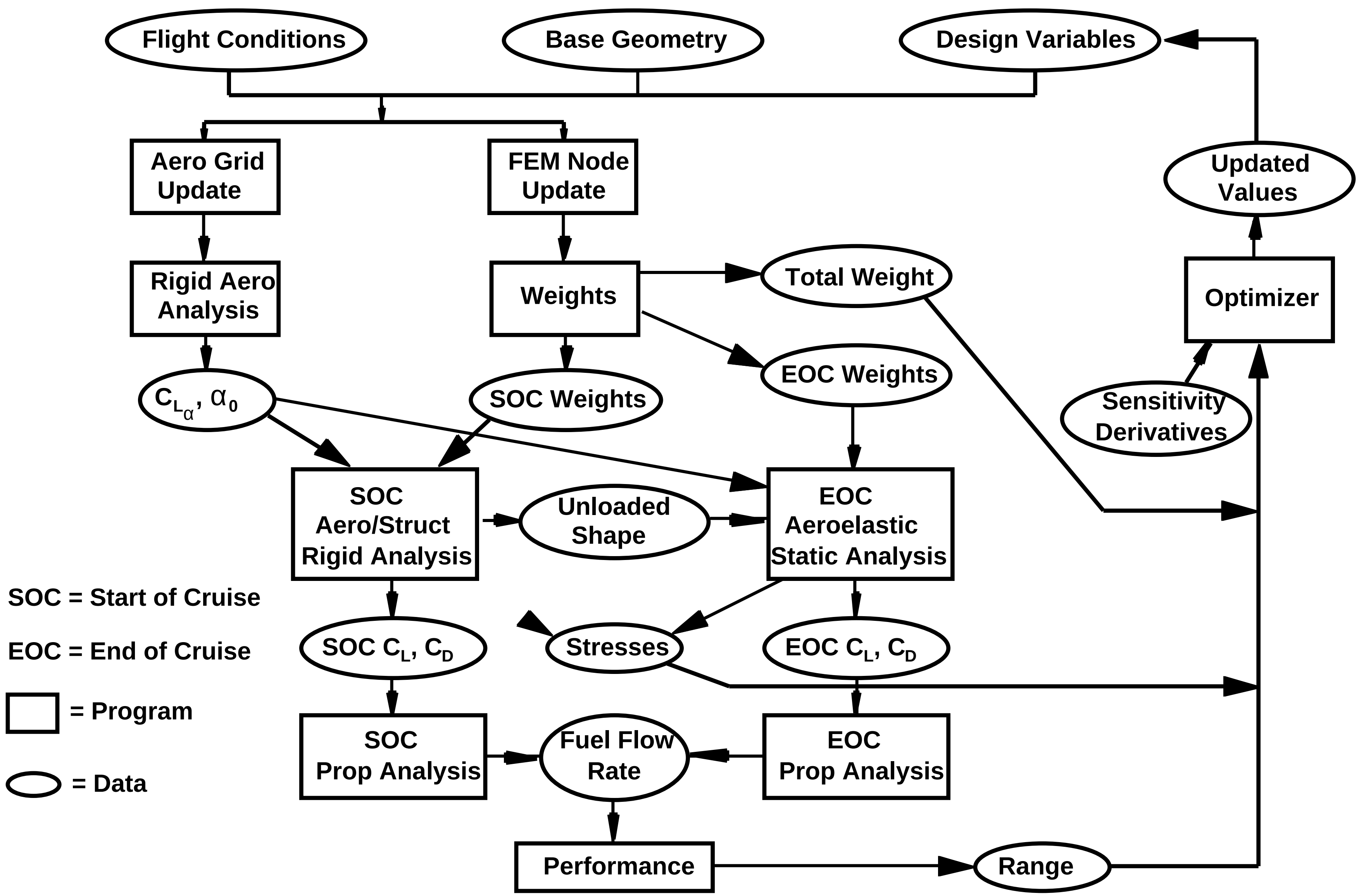
Projected FY 98 Developments

- Derivation of consistent structural/aerodynamic models, with exact geometric derivatives automatically available
- Single-point configuration optimization with respect to structural/aerodynamic variables with high-fidelity codes, based on multipoint performance calculations
- Optimization of strongly coupled nonlinear problems with on the order of 200 design variables
- Calculations of trimmed elastic loads with nonlinear corrections
- Parallel execution of computationally intensive analysis/sensitivity analysis codes

Projected FY 99-00 Capability

- Derivation of consistent structural/aerodynamic models tied to a unique parametric model with exact geometric derivatives
- Single-point configuration optimization with respect to structural/ aerodynamic variables with high-fidelity codes, based on multipoint performance calculations
- Optimization of strongly coupled nonlinear problems with on the order of 200 variables
- Calculations of trimmed elastic loads with Navier-Stokes corrections
- Linear flutter calculations
- Parallel execution of computationally intensive analysis/sensitivity analysis codes
- Application of a commercial optimization framework
- Potential inclusion of
  - propulsion
  - controls
  - cost
  - multi-point/multi-objective optimization

HSCT 3.5 Problem Diagram

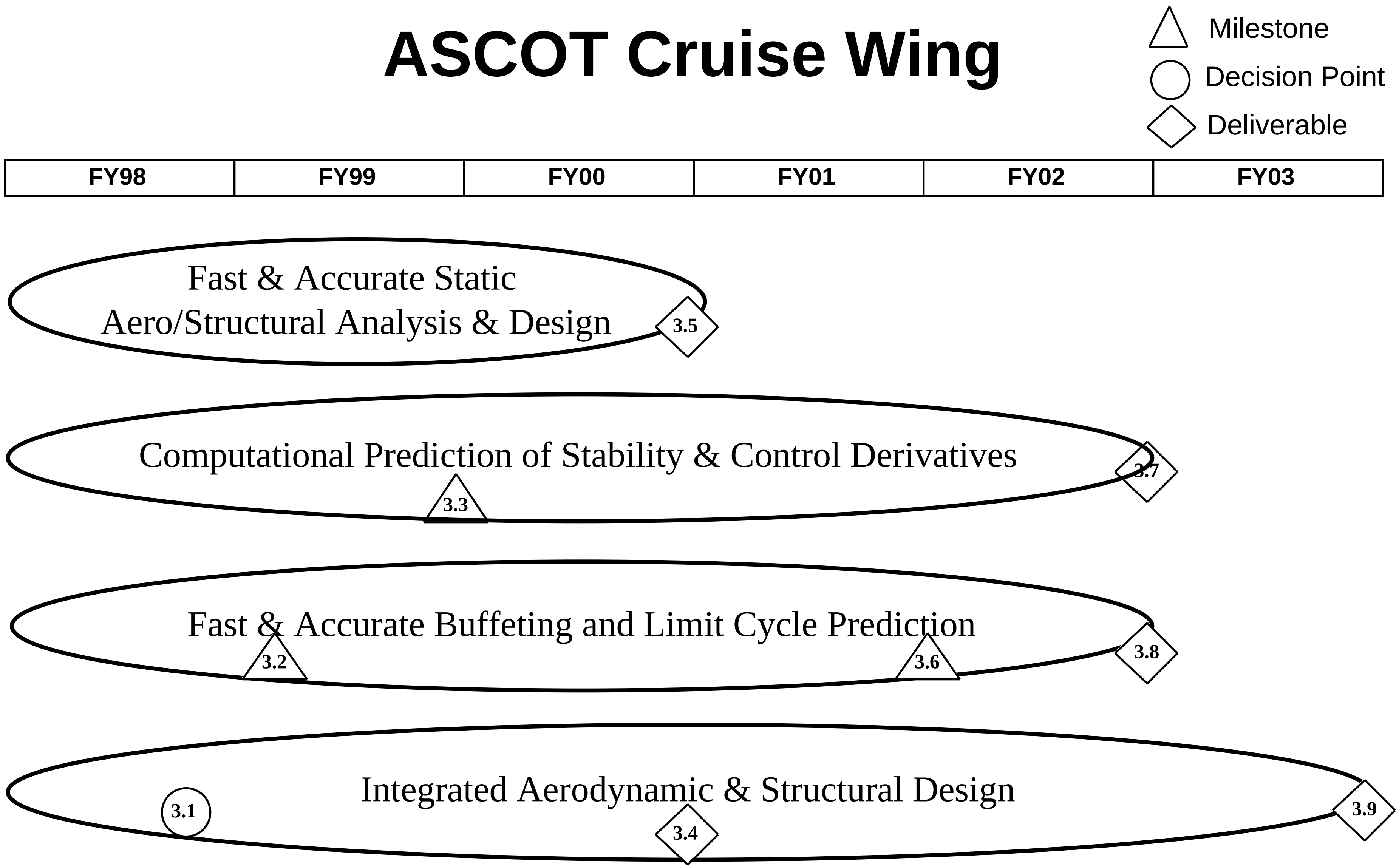


MDOB ASCOT Activities

ASCOT Cruise Wing Goals

- **Fast & Accurate Static Aero/Structural Analysis & Design**
  - **Reduce the number of cycles for high-fidelity static aerostructural solution from 20 cycles to 2 cycles**
  - **Achieve high-fidelity static aerostructural optimization in less than 10 work units**
- **Computational Prediction of Stability & Control Derivatives**
  - **Increase the % of CFD-derived stability & control derivatives from 99% exp. / 1%CFD to 40% exp. /60%CFD**
- ***Fast & Accurate Buffeting and Limit Cycle Prediction [AB/SD & AAMB/ FMAD]***
  - ***Improve accuracy of separation onset and vehicle response Mach No. to $\Delta M = 0.02$***
  - ***Improve accuracy of separation onset and vehicle response a prediction to $\Delta\alpha = \pm 0.25°$***
  - ***Reduce the time required to predict separation onset and vehicle response to < 3 hrs/ Mach no.***
- **Integrated Aerodynamic, Structural & Aeroelastic Design**
  - **Reduce the time to equip a CFD or Computational Aeroelasticity code with accurate, efficient adjoint code from 6 months to1 week**
  - **Improve efficiency of high-fidelity MDO by reducing calls to hi-fi code / cycle from 1 to 0.1**
  - **Demonstrate feasibility high-fidelity aerodynamic, structural & aeroelastic optimization**

ASCOT Cruise Wing

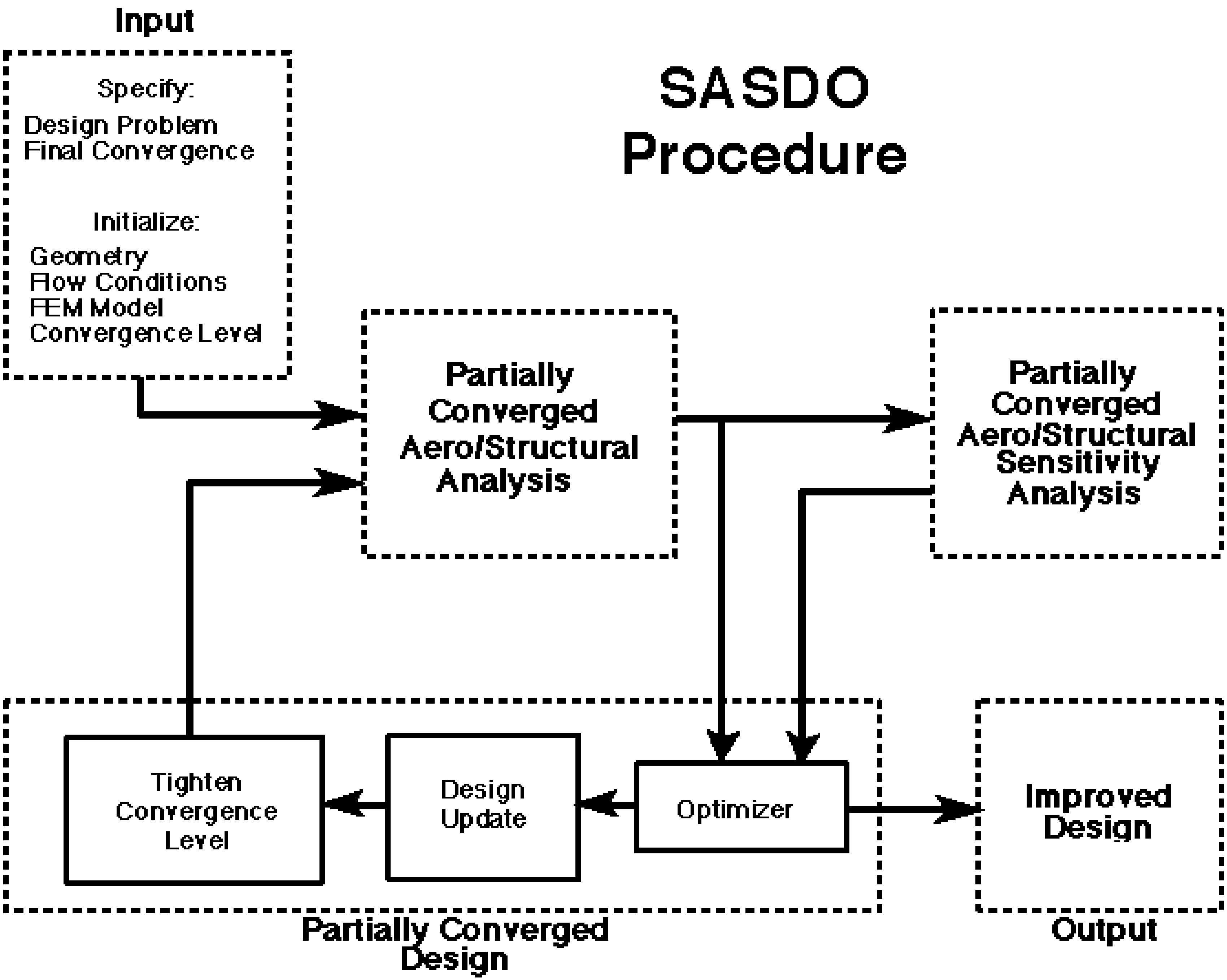


Cruise Wing Milestones

Milestones	Qtr	FY
3.1. Demonstrate ADJIFOR on CFL3D to produce adjoint code used in optimization (DP)	3	98
3.2. Complete assessment of IBL capability for 3-D buffet onset	1	99
3.3. Demonstrate dynamic S&C derivatives (rate derivatives) from panel code (MS)	4	99
3.4. Demonstration results from MDO approximation toolkit for nonlinear problems	4	00
3.5. Fast & accurate static aero/structural optimization demonstrated	4	00
3.6. Validation study of non-stationary flows turbulence model	4	01
3.7. Computational prediction of stability & control derivatives demonstrated	4	02
3.8. Fast & accurate methods for buffeting & limit cycle oscillation (LCO) demonstrated	4	01
3.9. Integrated aerodynamic and structural design developed	4	03
Technology in place to analyze & optimize cruise wing configuration for aero/structures, aeroelasticity and stability & control		

MDOB ASCOT Activities

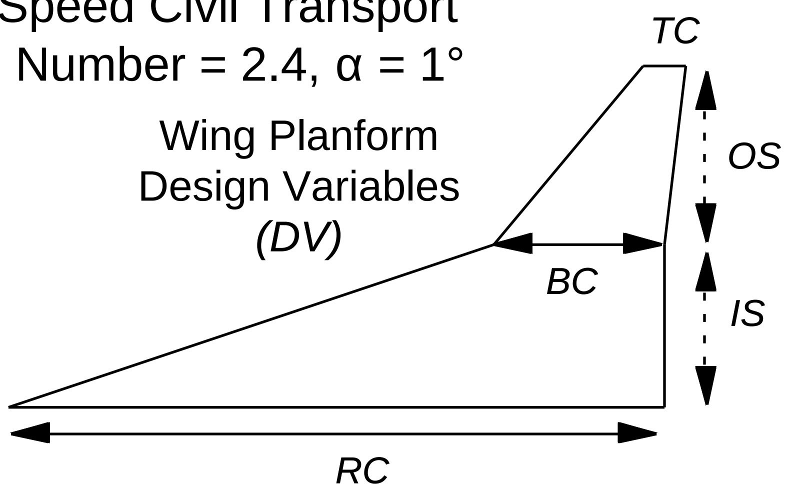
- **Simultaneous Aerodynamic and Structural Design Optimization (SASDO)**
  - Enable high-fidelity aerodynamic and (static) structural optimization to be conducted simultaneously at the cost of a few (static) aeroelastic analyses
- **Stability and Control Derivatives from CFD Codes**
  - Develop basic approach to extracting all stability & control derivatives from IBL & Navier-Stokes CFD codes and enable efficient, accurate extraction of requisite stability & control derivatives from Navier-Stokes CFD codes
- **Automatic Differentiation**
  - Enable conventional analysis codes to be rapidly augmented with accurate and efficient gradient, adjoint & Hessian code
- **Approximation Validation and Management**
  - Enable use of approximation methods that exploit high-fidelity nonlinear analyses and experimental results in efficient multidisciplinary optimization applications
- **Static & Dynamic Aero/Structural Optimization (FY 00 start)**
  - Develop an automated method to optimize the cruise wing configuration for static aerostructural performance with flutter constraints


Input
Specify:
Design Problem
Final Convergence
Initialize:
Geometry
Flow Conditions
FEM Model
Convergence Level
SASDO
Procedure
Partially
Converged
Aero/Structural
Analysis
Partially
Converged
Aero/Structural
Sensitivity
Analysis
Tighten
Convergence
Level
Design
Update
Optimizer
Improved
Design
Partially Converged
Design
Output

Automatic Differentiation of 3-Dimensional Navier-Stokes Flow Code (CFL3D)

High Speed Civil Transport
Mach Number = 2.4, α = 1°

Wing Planform
Design Variables
(DV)



Aerodynamic Coefficients	
C_L	Lift
C_D	Drag
C_Y	Side Force
CM_Y	Pitching Moment

Sensitivity Derivatives - Derivatives of Aerodynamic Coefficients
With Respect to Wing Planform Variables

$$\frac{\partial CL}{\partial DV} \quad \frac{\partial CD}{\partial DV} \quad \frac{\partial C_y}{\partial DV} \quad \frac{\partial CM_y}{\partial DV}$$

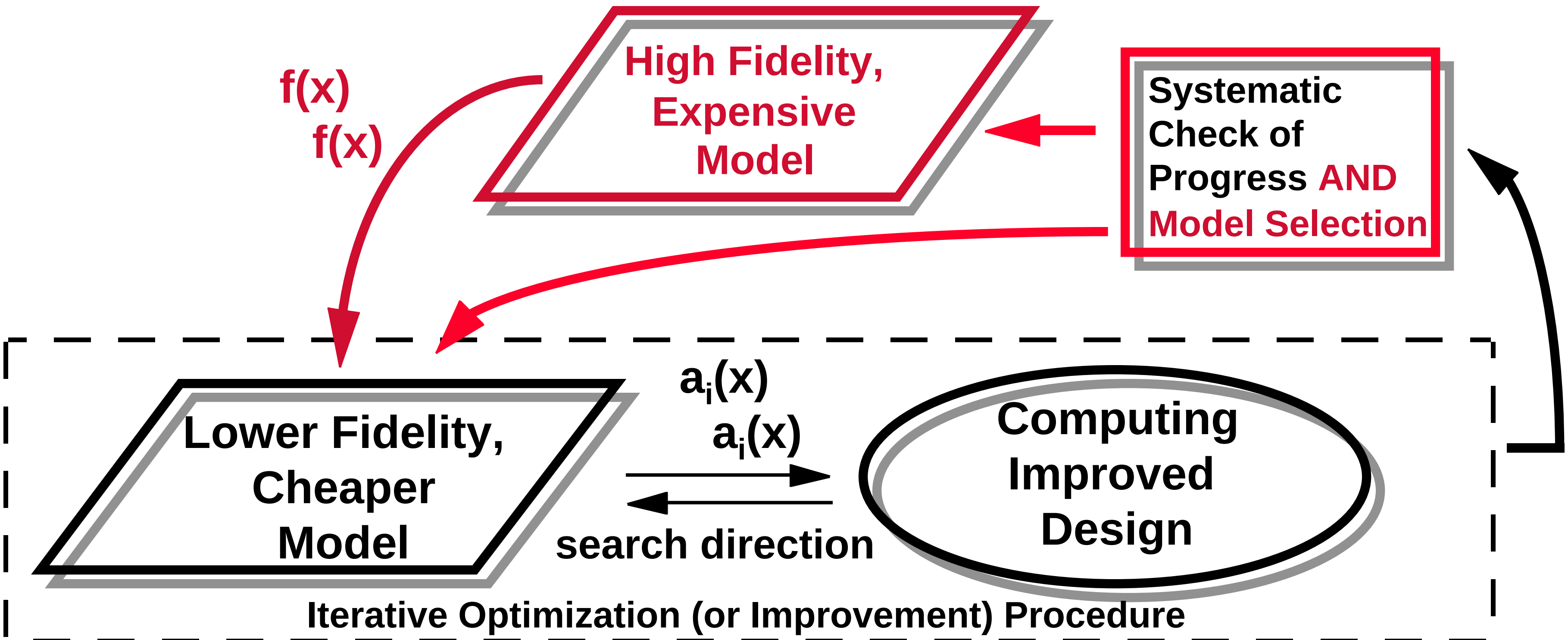
Time to Compute Sensitivity Derivatives (for 4 digits of Accuracy)

Automatic Differentiation (Residual reduced 4 orders) = 10.75 units
Finite Difference Method (Residual reduced 11 orders) = 15.00 units

Approximation Model Management for MDO

$f(x)$ - high fidelity, expensive model, such as analysis or simulation

$a_i(x)$ - one of the suite of lower fidelity or accuracy models of the same physical process



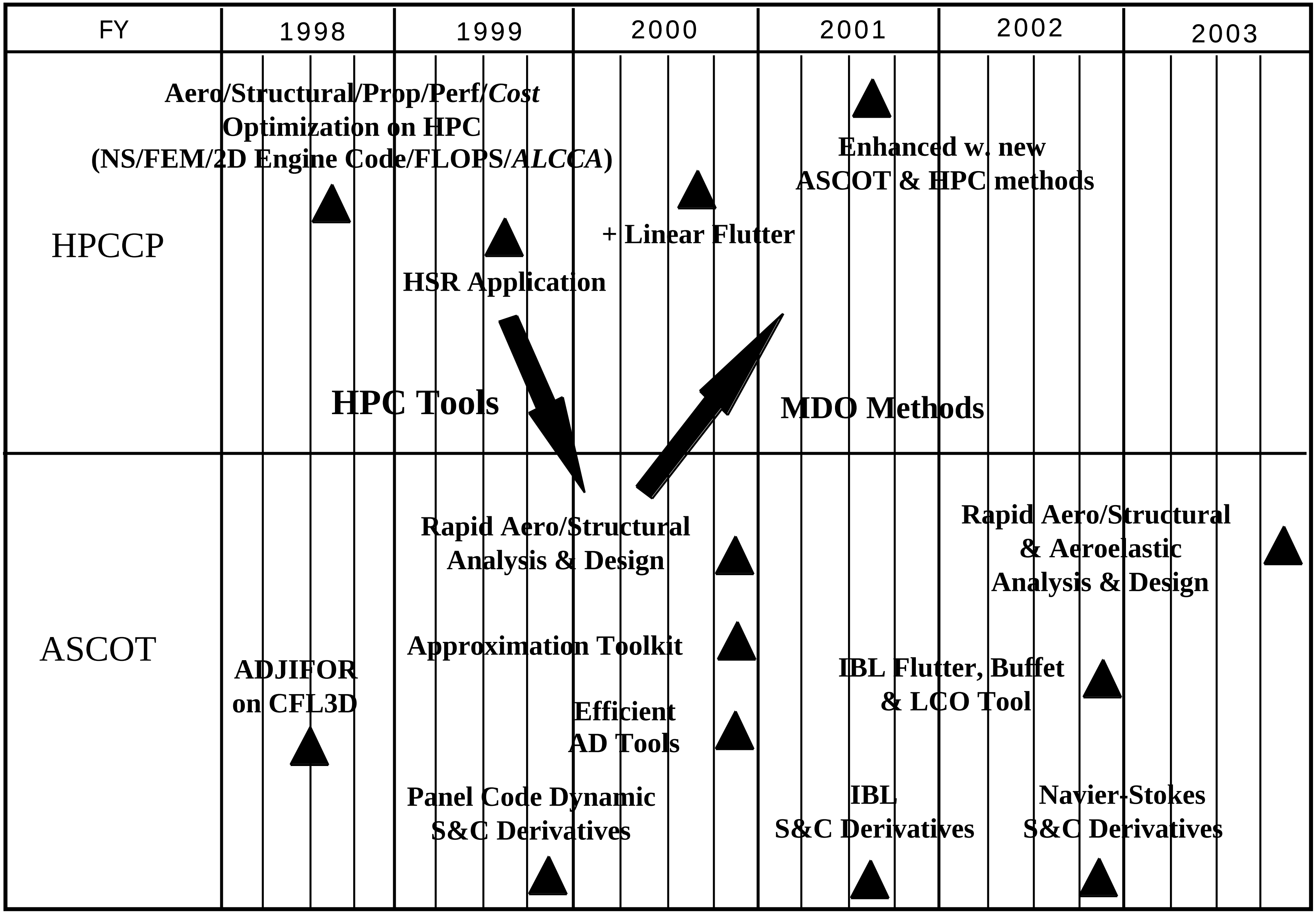
Result: Systematic use of inexpensive models in the repetitive process with only occasional recourse to expensive models yields convergence to critical points of expensive models without the conventional expense.

ASCOT - HPCCP Linkage

ASCOT MDO Methods & Tools	→	**HPCCP** HPC demos of MDO w. selected discipline & MDO codes
HPCCP HPC capability CAD linkage HPC MDO Methods	→	**ASCOT** HPC & CAD used in MDO

HPCCP will only undertake parallelization of selected discipline codes & MDO methods as needed for HPC demonstrations

MDO Roadmap



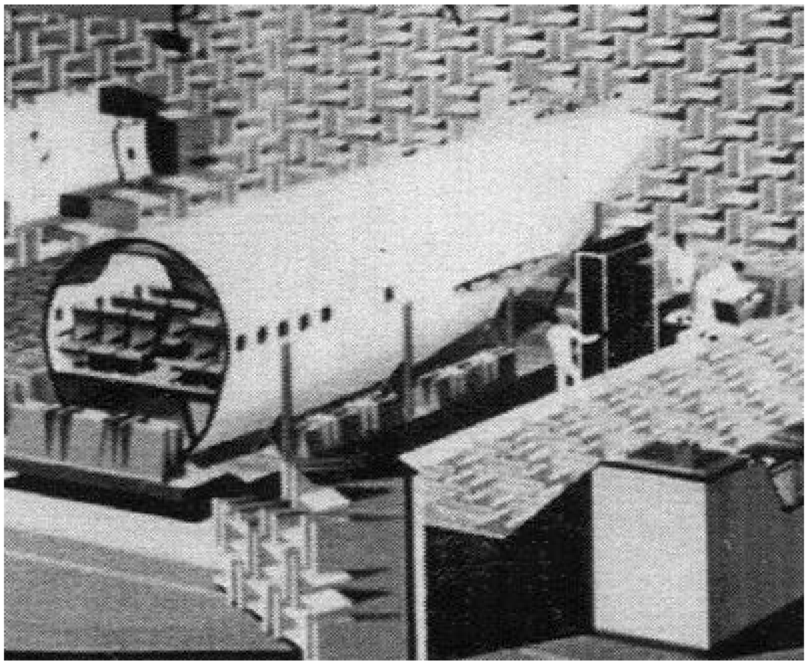
FY
1998
1999
2000
2001
2002
2003
HPCCP
Aero/Structural/Prop/Perf/*Cost*
Optimization on HPC
(NS/FEM/2D Engine Code/FLOPS/*ALCCA*)
HSR Application
+ Linear Flutter
Enhanced w. new
ASCOT & HPC methods
HPC Tools
MDO Methods
ASCOT
ADJIFOR
on CFL3D
Rapid Aero/Structural
Analysis & Design
Approximation Toolkit
Efficient
AD Tools
Panel Code Dynamic
S&C Derivatives
Rapid Aero/Structural
& Aeroelastic
Analysis & Design
IBL Flutter, Buffet
& LCO Tool
IBL
S&C Derivatives
Navier-Stokes
S&C Derivatives

MDOB Aircraft Morphing Activities

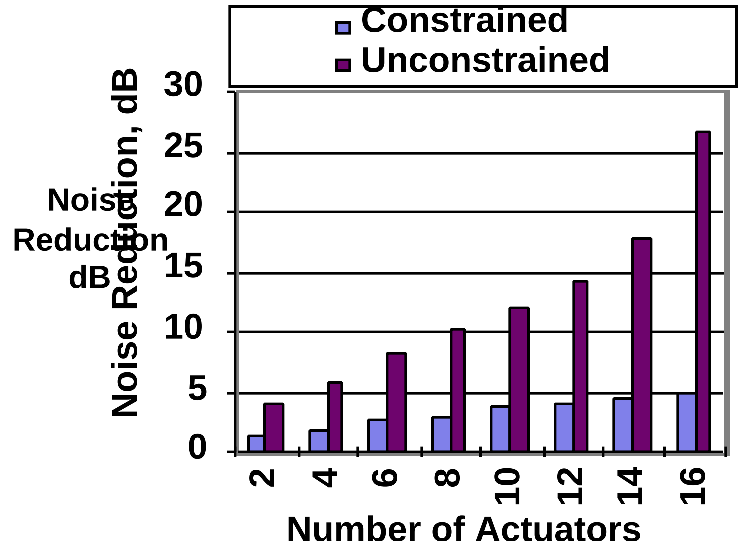
Multidisciplinary Optimization of Smart Devices and Control Architectures

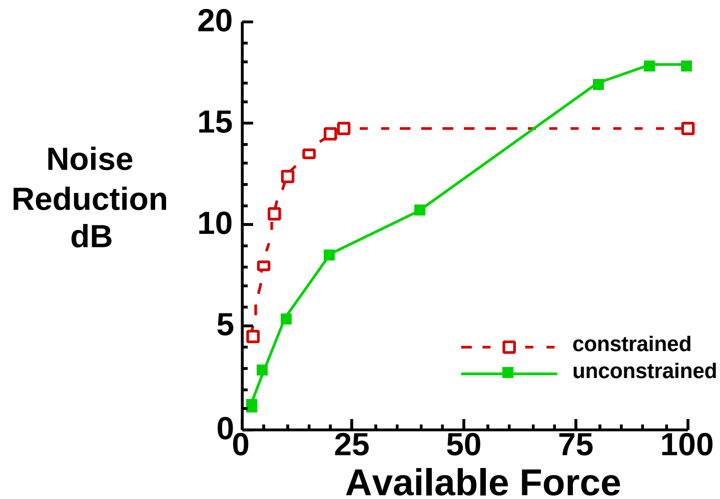
- **Objective**
  - Optimize the location and design of smart actuators and sensors for best integrated response
- **Approach**
  - Use discrete optimization plus measured transfer functions or continuous optimization plus analytic simulations to predict the best set of sensor/actuator locations for active control.
  - Use existing MDO tool kit to improve effectiveness, weight or power requirements of individual smart devices.
  - Develop new methods to manage the uncertainties associated with subcomponents and to predict the impact of all uncertainties on system design.
- **Related Work**
  - This is a new start in FY 98
  - During FY 96-97 MDOB worked with the Structural Acoustics Branch in applying discrete optimization methods to the reduction of interior noise
  - The following slide illustrates that related work

Optimized Actuator Array for Control of Multi-frequency Noise



Fuselage Acoustic Research Facility



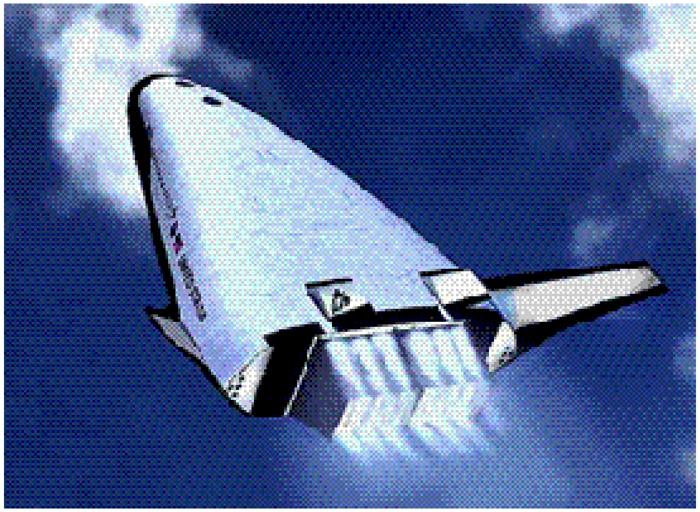


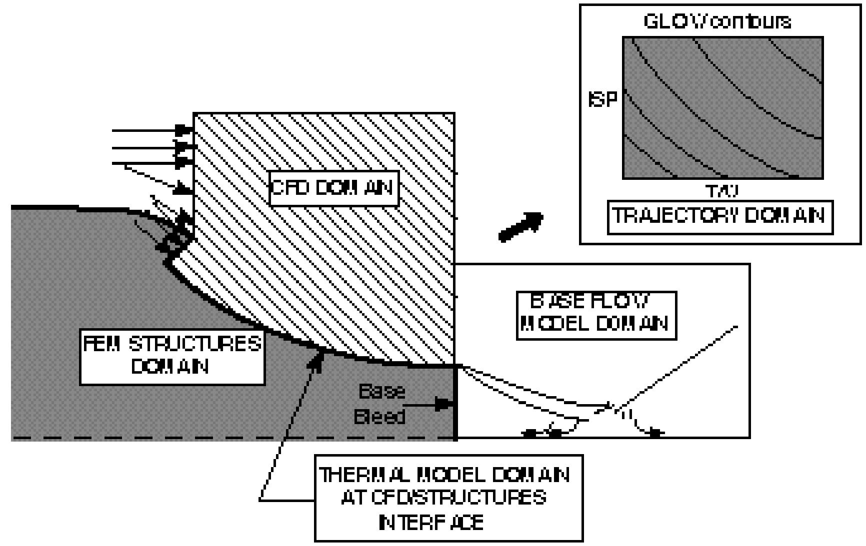
MDOB RLV Activities

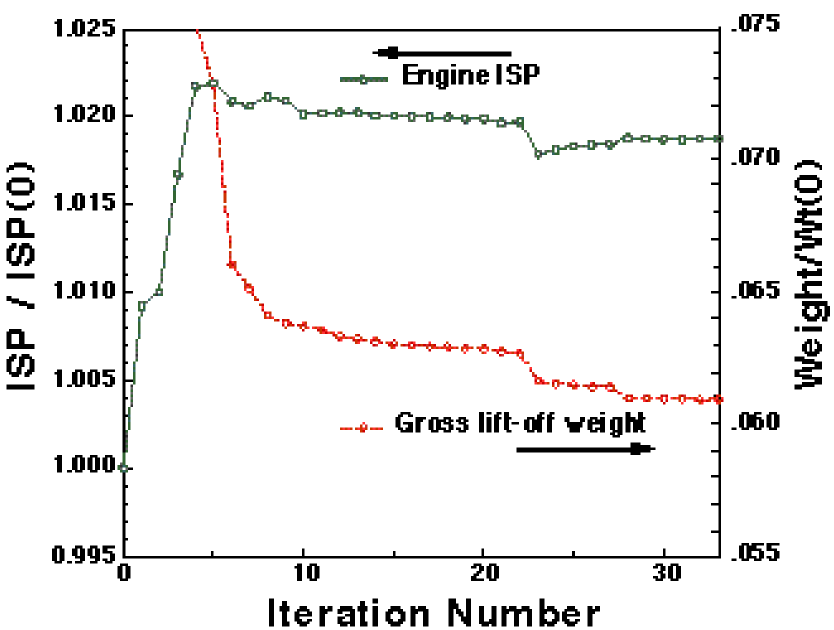
FY 98-99 RLV Tasks

- MDOB is supporting a joint LaRC/Lockheed-Martin/ Rocketdyne activity on RLV design led by the LaRC Vehicle Analysis Branch of the Space Systems Concepts Division
- The MDOB role is the development and integration of aerospike engine analysis and optimization tools into the conceptual design process
  - developing a parametric engine module for engine performance prediction across the trajectory
  - optimization of engine design across the trajectory
- This builds on past MDOB work on demonstrating aero-structural optimization of an aerospike nozzle, as illustrated on the following 2 slides

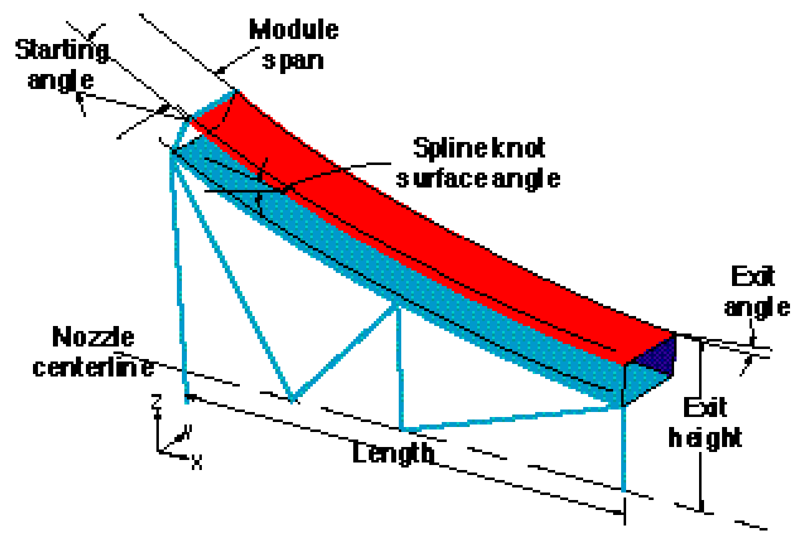
Multidisciplinary Model of an Aerospike Nozzle



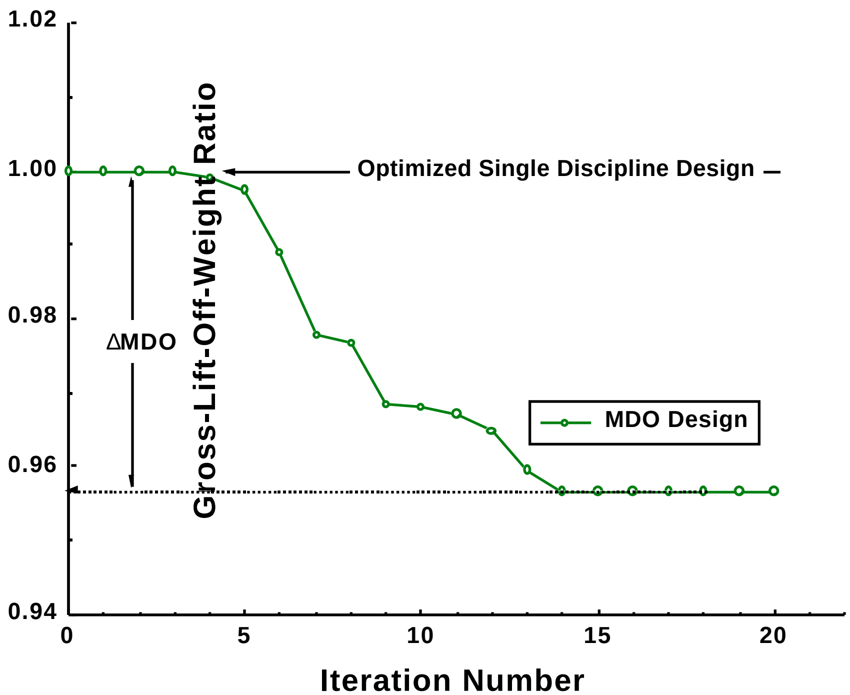




Nozzle Geometry Design Variables



MDO Impact on Aerospike Nozzle



- **Single Discipline Design**
  - **optimize the aero shape for maximum Isp**
  - **then optimize the structure for minimum GLOW**
- **MDO Design**
  - **optimize the aero & structures together for minimum GLOW**
  - **produces 4% reduction in GLOW**